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TRANSPORT OF CRITICALLY ILL MECHANICALLY VENTILATED ilability Codes
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Critically ill, mechanically ventilated, patients were monitored with manometry, spirometry, and capnography during intrahospital transport out of the ICU. Patients functioned as their own control, and medical personnel were "blinded" to capnography for 50% of the transport time. During the "blinded" time, all patients developed a respiratory acidosis. Use of the non-invasive monitor, the capnograph prevented this adverse effect and resulted in improved patient safety. The study also revealed that the percentage of "dead space" did not increase during transport, and that rebreathing of exhaled carbon dioxide was a frequent event with the use of the Jackson-Rees breathing circuit.

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Daniel P Stoltyfus MAJMC 15 December 1992
Principal Investigator's Signature   Date

Abstract Page:

The objective of this protocol was to evaluate the role of a portable, non-invasive monitor (capnograph) in guiding manual ventilatory support during the intra-hospital transport of critically ill, mechanically ventilated patients. This prospective, consecutive, study consisted of 105 ventilation episodes during the intra-hospital transport of 13 patients from the Surgical ICU of Walter Reed Army Medical Center during 1991 and 1992.

Manual ventilation was provided without specific guidance during 50% of the time of a patient's intrahospital transport (transport A). During the remaining transport time (transport B) medical personnel were instructed to provide sufficient manual ventilation to achieve an end-tidal carbon dioxide level equal to the patient's measured level in the ICU. With each patient functioning as their own control, measurements of end-tidal carbon dioxide ($ETCO_2$), minute ventilation (MV), peak inspiratory pressure (PIP), fraction of inspired oxygen concentration (FIO_2) and peripheral arterial oxygen saturation (S_aO_2) were made in the ICU (baseline), and during intrahospital transport (A and B). Patients had three blood gas analyses of arterial partial pressure of oxygen (p_aO_2), arterial partial pressure of carbon dioxide (p_aCO_2), and pH.

The mean change in the p_aCO_2 and pH was greater during transport A (13 $\pm$ 12 torr, and .10 $\pm$ .09, respectively) than during transport B. (5.0 $\pm$ 8 torr and 0.04 $\pm$ .04, respectively).

A stable end-tidal carbon dioxide level was achieved during transport by the provision of an increased minute ventilation. During manual ventilation, the increased minute ventilation was obtained by a change in the tidal volume without a concomitant increase in the peak inspiratory pressure.

In conclusion, during intrahospital transport of mechanically ventilated patients, without guidance in manual ventilation, all patients developed respiratory acidoses. Capnography uniformly prevented the development of respiratory acidosis during transport. We recommend that use of a capnograph should be considered during the intrahospital transport of all critically ill, mechanically ventilated patients. The relevance to military medical operations relates to the care of critically injured soldiers, who require transportation following the provision of an artificial airway (endotracheal tube or tracheostomy) either in the field of operations, or later during definitive medical care.

INTRODUCTION

It is commonly accepted that transporting critically ill patients outside of the ICU poses significant risks to the patient. As high as 68% of all ICU patient transports result in serious physiologic changes of 5 minutes duration[1], and as many as 70% of critically ill patients manually ventilated during intrahospital transport develop significant alterations in either arterial carbon dioxide levels or pH[2].

We postulated that the use of capnography during the intrahospital transport of critically ill, mechanically ventilated patients would prevent the development of clinically significant acidosis.

MATERIALS AND METHODS:

Study Population:

The study population consisted of 13 consecutive, mechanically ventilated patients, scheduled for 15 diagnostic studies, who required intrahospital transport outside of the Surgical ICU. The study was approved by the Clinical Investigation and Human Use Committees of Walter Reed Army Medical Center, the U.S. Army Health Services Command, the Office of The Army Surgeon General, and the U.S. Army Medical Research and Development Command. As these patients had lost decision making capacity, the patients' surrogate decision makers were counselled regarding the risks and benefits of the study, and provided written informed consent.

Measurements:

Prior to transport, a portable capnograph (Datex Normocap 200, Tewksbury, MA), a spirometer (Boehringer #8800, Norristown, PA), and a manometer (Posey #8199 Elk Grove Village, IL.), were connected to the patient breathing circuit (Figure 1). Patients were also continuously monitored with a pulse oximeter (Marquette Electronics TRAM monitor #200, Milwaukee, WI.) Baseline values of minute ventilation (MV), respiratory rate (RR), fraction of inspired oxygen concentration (FIO_2), peak inspiratory pressure (PIP), peripheral arterial oxygen saturation (S_aO_2), end-tidal carbon dioxide level ($ETCO_2$), arterial partial pressure of oxygen (p_aO_2), arterial partial pressure of carbon dioxide (p_aCO_2), and pH were obtained while the patient was stable on mechanical ventilatory support, and just prior to transport. All patients were ventilated using the synchronized intermittent mandatory ventilation mode (SIMV) of the PB 7200 ventilator (Puritan Bennett, Los Angelos, CA).

During transport from the ICU to the location of diagnostic study (transport A), the health care provider responsible for manual ventilation of the patient was given no specific instructions. The patient's S_aO_2, $ETCO_2$, and the capnograph waveforms were continuously monitored. The PIP, exhaled minute volume, and the assisted and total respiratory rates were collected by the research team at least three times during

transport, at approximately 5 minute intervals. The capnograph was shielded from the view of the responsible medical team.

Upon arrival to the location of diagnostic study an arterial blood gas (ABG) was obtained prior to the reinstitution of mechanical ventilation. Mechanical ventilatory support, equivalent to that provided during the measurement of the ICU baseline, was provided for the duration of the diagnostic procedure. Prior to the return transport to the ICU, new baseline values of MV, PIP, RR, S_aO_2 and $ETCO_2$ were obtained. During this return transport (transport B) the capnograph was made visible to the health care provider who was instructed to ventilate the patient in a manner that would maintain the $ETCO_2$ equal to the stable ICU baseline. The patients' S_aO_2, $ETCO_2$ and capnograph waveforms were again recorded continuously. The MV, PIP, and RR were recorded at least three times, at approximately 5 minute intervals, during this transport. An arterial blood gas was obtained upon return to the ICU, prior to the reinstitution of mechanical ventilation.

Per Surgical ICU protocol, all patients were accompanied by a physician and an ICU nurse during transport outside of the ICU. At Walter Reed Army Medical Center, only one respiratory therapist is available during transports, and is responsible for establishing mechanical ventilation at locations outside of the ICU. All patients were transported with a Mapleson F (Jackson-Rees) breathing circuit at an $FIO_2 = 1.0$.

Calculations:

The equations used to calculate the percent of dead space ventilation (V_D/V_T, the alveolar-arterial oxygen difference ($A-aDO_2$), and the ratio of arterial partial pressure of oxygen to alveolar partial pressure of oxygen (p_aO_2/p_AO_2) are as follows: $V_D/V_T = (P_aCO_2 - P_{et}CO_2)/P_aCO_2$; $AaDO_2 = [F_IO_2 (P_B-P_{H2O}) - P_aCO_2 /0.8] - P_aO_2$; $P_{aO}2/P_AO_2 = P_aO_2/[F_IO_2 (P_B-P_{H2O}) - p_aCO_2/0.8]$ where V_D is dead space, V_T is tidal volume, $P_{et}CO_2$ is the end-tidal carbon dioxide level, P_B is barometric pressure, and P_{H2O} is partial pressure of water vapor.

Statistics:

Differences between means during ICU stay, transport A (no instruction), and transport B (capnography directed manual ventilation) were examined by repeated measures analysis of variance. Pairwise comparison were made using the paired t-test with a Bonferroni adjustment. All P values are two-sided, with $P < 0.05$ considered significant.

RESULTS:

Thirteen patients, scheduled for 15 consecutive diagnostic studies, were prospectively studied. There were 9 males and 4 females, with a mean age was 67($\pm$ 9) years. The mean ICU baseline minute ventilatory requirement of these patients was 13.6 L/min ($\pm$ 3.7), with a range from 7.8 - 22 L/min. Table 1 lists the ventilatory support settings, arterial blood gas

analyses and the end-tidal carbon dioxide values in the ICU and following transports A and B.

In comparison to their ICU baseline values, all patients developed hypercapnia and a respiratory acidosis following transport A (Figures 2,3). The maximum changes in p_aCO_2 and pH following transport A were +36 torr and -.30, respectively. Compared to the ICU baseline, no significant hypercarbia occurred when capnography directed the manual ventilation (p=.12). There was no significant difference from the baseline ICU value of either respiratory rate (p=.21). The increased minute ventilation required to maintain an $ETCO^2$ level equivalent to the ICU baseline, was accomplished without an increase in the peak inspiratory pressure during manual ventilation (p= .127).

There was no significant change in the gradient of P_aCO_2 - $P_{et}CO_2$ at any time during manual ventilation (p=.20) indicating no change in the percentage of dead space ventilation. The mean times for transport A and B were 15 and 14 minutes respectively. The mean total time these patients were outside of the ICU for diagnostic studies was 84 minutes.

No patient experienced hypoxemia, since an increased FIO_2 was provided, and there was no deterioration in alveolar gas exchange as calculated by p_aO_2/p_AO_2.

DISCUSSION:

Gervais et al[3] demonstrated that respiratory alkalosis developed when ICU patients were manually ventilated, without

spirometric measurement of tidal volume, or a transport ventilator. Weg et al[4], did not observe significant alterations in the arterial blood gas values during intrahospital transport with manual ventilatory support. These authors accepted an arterial blood gas value, within an 8 hour time period prior to transport, as the patient's baseline. We were not willing to make this assumption in critically ill patients. In our study, respiratory acidosis uniformly occurred during the intrahospital transport of critically ill, mechanically ventilated patients when capnography was not used.

The finding of respiratory acidoses is in contradistinction to other authors. Possibilities to explain this respiratory acidosis during transport include the following: hypoventilation, an increase in the carbon dioxide production, an increase in dead space ventilation, and re-breathing of carbon dioxide in the respiratory circuit. Our patients were not hypoventilated during transport A, as the minute ventilation was not significantly different from the ICU baseline. The calculated values for the percentage of dead space ventilation were not significantly different during transports A and B, in comparison to the ICU baseline. Re-breathing of carbon dioxide was noted on the capnography waveform during 11/15 transport episodes, and has been previously described during the use of the Jackson Rees breathing circuit.[5] We cannot exclude an increase in carbon dioxide production as a contributing cause for the hypercarbia during intra-hospital transport. The majority of our patients

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were sedated prior to, and during, transport, however, the mechanical effect of moving our patients could have increased their metabolic rate and carbon dioxide production. The addition of a capnograph, and a minimal amount of instruction, prevented the development of respiratory acidosis during patient transport outside of the ICU. The continuously displayed capnograph provided real-time information regarding the adequacy of assisted ventilation. Medical personnel with minimal training, easily adjusted the amount of ventilatory support to maintain an $ETCO_2$ level equal to the patient's ICU baseline. The increased minute ventilatory need, reported in our study, makes it practical to add a capnograph to the transport armamentarium. Should the use of capnography really be credited for the significant difference in our patient's arterial carbon dioxide and pH status, or were there other potential contributing factors? We do not believe a "learning bias" contributed to better patient homeostasis during transport B. All medical staff, except the research team, were blinded to data collected during transport A, and were unaware of the hypothesis of our study.

Although a new baseline of p_aCO_2 and p_H was not measured, we believe that these patients were restored to their ICU baseline. The mean time of mechanical ventilation, with identical ICU settings, during the diagnostic study, was 55 minutes, and there was no significant difference between the $ETCO_2$ prior to transport B and the ICU baseline (p=.51). Since the use of capnographs for all transports outside of the

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ICU would represent a financial investment a reasonable question
is whether their use results in an outcome difference for
patients. We did not collect hemodynamic data and therefore
cannot address potential interactions between a respiratory
acidosis and other adverse patient outcomes. However, no
patients developed a life threatening dysrhythmia, and there were
no deaths during intrahospital transport.

CONCLUSION:

Critically ill, mechanically ventilated patients,
transported outside of the ICU, frequently develop respiratory
acidosis. This physiologic aberration could be clinically
significant for some patients, especially those suspected of
having increased intracranial pressure. The development of this
respiratory acidosis during intrahospital transport of critically
ill patients may be reliably avoided by the use of capnography.
We recommend that use of a capnograph should be considered during
intrahospital transport of all critically ill, mechanically
ventilated patients.

MILITARY RELEVANCE:

The findings of this study have significant military
relevance. A small, but significant, percentage of combat
casualties may require endotracheal intubation or tracheostomy,
followed by mechanical ventilation. Most of these patients will
then require transportation out of the field of operation, back

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to a combat support hospital or similiar facility. Transport capable ventilators have not been reliably available during previous conflicts (personal communication, Operation Desert Storm). Given the unpredicatability of military engagements, military medical personnel may have little formal training or experience in providing manual ventilation to these patients. Thus it is of significant importance to have a reliable and portable monitor which can ensure that sufficient ventilation is provided to these patients during transport. The Datex Capnograph, Normocap 300 that we tested would fulfill this purpose.

An additional consideration during transport of the combat casualty who has sustained a respiratory insult sufficient to require mechanical ventilation, is the extremely limited ability to monitor patients during helicopter transports. In this situation, medical personnel are unable to even auscultate a patient's lungs to confirm sufficient ventilation. Thus, a portable and continuous monitor of exhaled carbon dioxide ensures that the patient has not been accidentally extubated, and is receiving adequate ventilation.

Table 1   Baseline and Transport Ventilation Data

	ICU Baseline	Transport A	Transport B	P value
MV	13.6 ± 3.7	12.9 ± 5.8	16.5 ± 5.6 *	0.032
RR	19.3 ± 8.4	22.1 ± 6.4	25.0 ± 6.7	0.100
PIP	36.2 ± 12.9	34.1 ± 13.2	43.4 ± 22.5	0.127
$ETCO_2$	33.5 ± 9.5	41.9 ± 7.0 [†]	34.5 ± 8.0 [‡]	0.004
p_aCO_2	37.5 ± 5.4	50.8 ± 12.5 [†]	42.4 ± 9.3 [‡]	0.005
pH	7.42 ± 0.08	7.31 ± 0.12[†]	7.38 ± 0.10[†‡]	0.003

Data are presented as mean ± standard deviation.
MV, minute ventilation; PIP, peak inspiratory pressure; RR, respiratory rate; $ETCO_2$, end-tidal carbon dioxide concentration; p_aCO_2, arterial partial pressure of carbon dioxide.

[†] significantly different from ICU baseline, P < 0.01
[*] significantly different from Transport A, P = 0.033
[‡] significantly different from Transport A, P < 0.02

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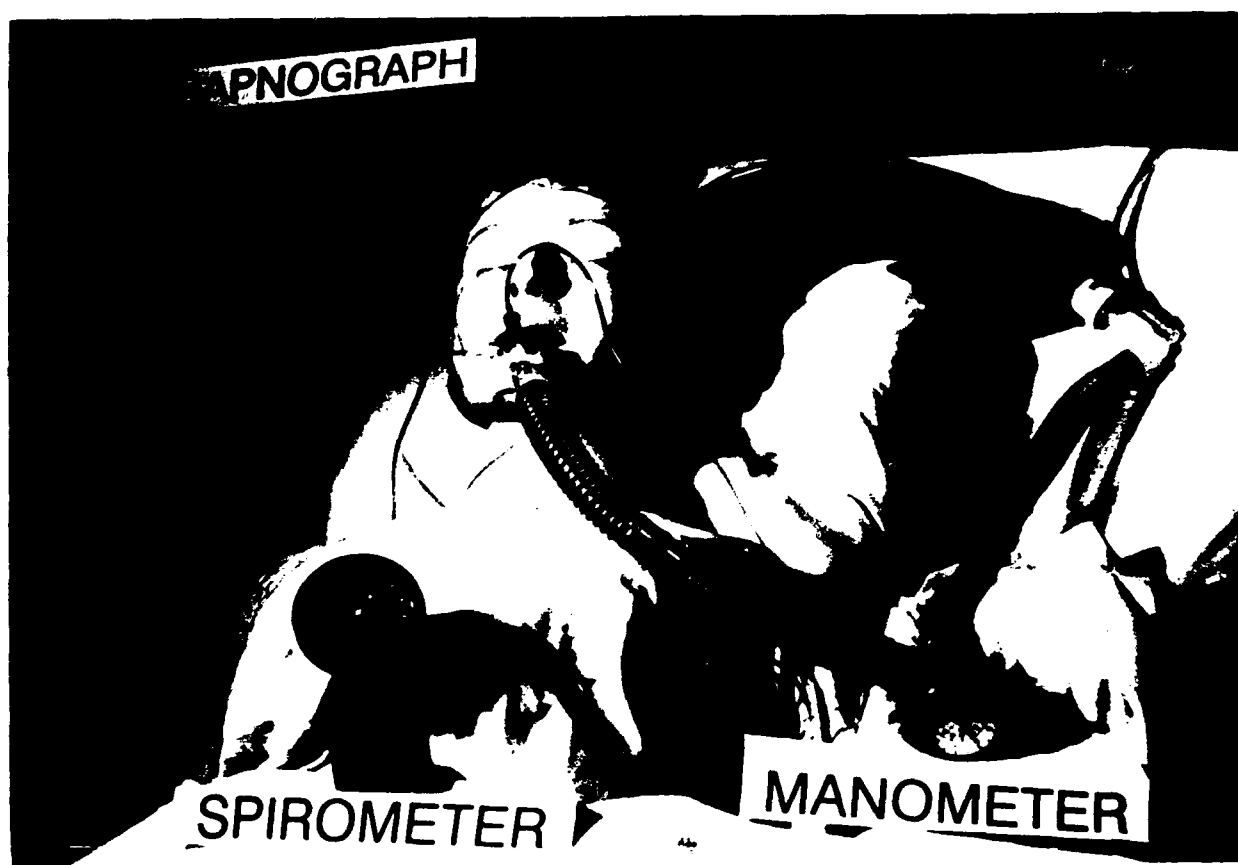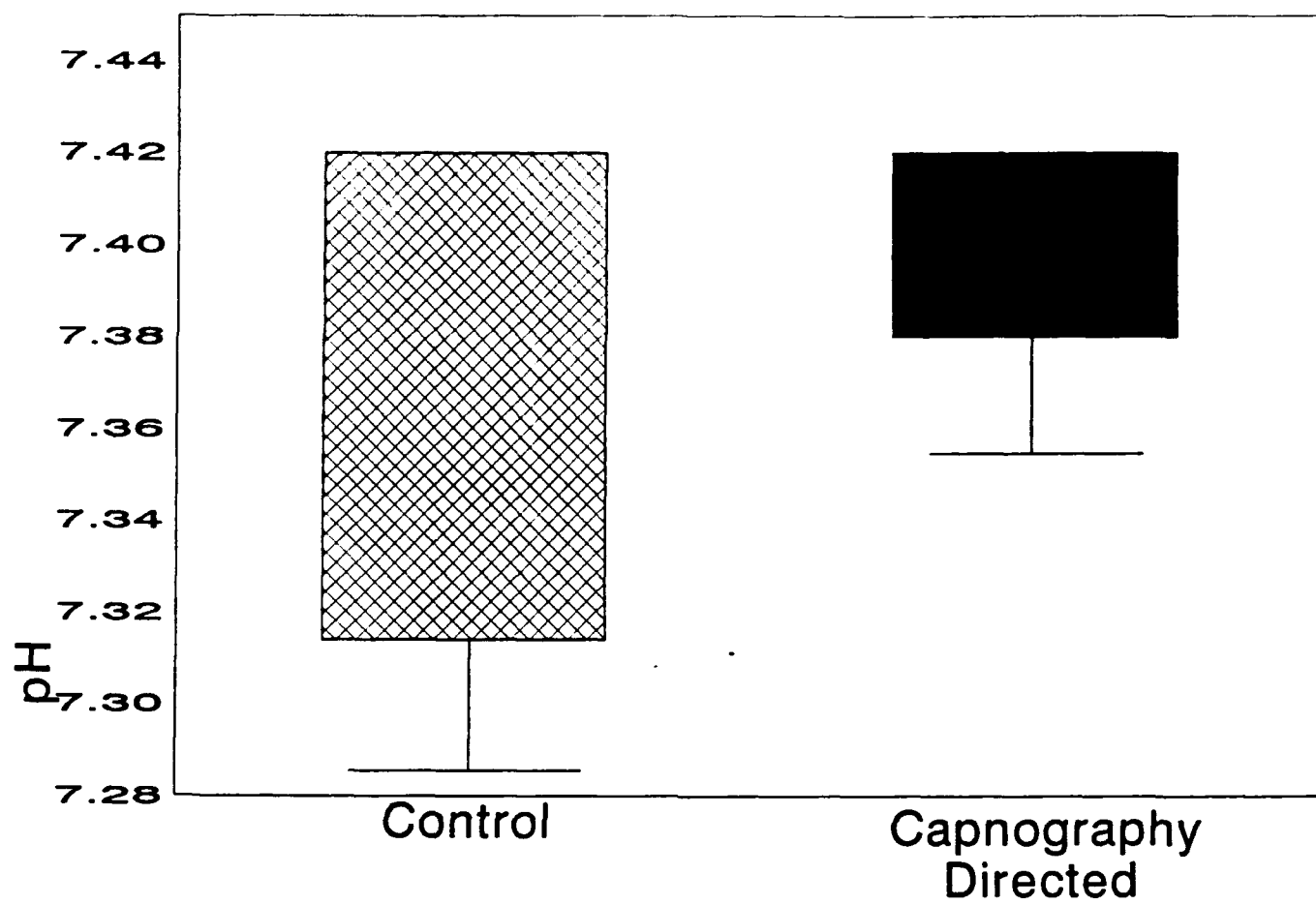
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